MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2018/2019

EME4016 – HEAT TRANSFER

(ME)

14 MARCH 2019
2.30 p.m. - 4.30 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question Paper consists of six pages including the cover page and appendix.

2. Answer ALL four questions. Each question carries 25 marks and the distribution of the marks for each question is given in brackets [ ].

3. Write all your answers in the Answer Booklet provided.

Question 1

(a) Derive the following equation for the temperature in an object that depends only on time and subjected to heat convection at the boundary. State the condition for the validity of this equation.

$\frac{T-T_\infty}{T_i-T_\infty} = e^{-\left(\frac{hA}{\rho V c}\right)t}$,

where symbols have their usual meanings.

[8 marks]

(b) A solid steel sphere 300 mm in diameter has thermal conductivity 48.8 W/m·K, density 7832 kg/m^3, and specific heat 559 J/kg·K. The sphere is initially at a uniform temperature of 500 °C, and is then suddenly quenched in a large oil bath for which the constant temperature is T_∞ = 100 °C, and h = 33.0 W/m^2·K. Estimate the time required for the sphere temperature to reach 140 °C.

[8 marks]

(c) The sphere in (b) is now coated with a dielectric material layer of thickness 2 mm and thermal conductivity 0.04 W/m·K, and the quenching process is repeated. Assuming the same initial conditions as before, how long does it take the sphere to cool down to 140 °C now?

Hint: Neglect the effect of energy storage in the dielectric material, since its thermal capacitance is small compared to that of the steel sphere.

[9 marks]

Continued...

Question 2

An electronic device is cooled by routing air at mass flow rate $\dot{m} = 1.5 \times 10^{-3}$ kg/s and inlet temperature, $T_i = 15$ °C through a circular tube of diameter $D = 10$ mm, and length $L = 0.20$ m, machined at the back of the device. Assume that a uniform heat flux $q_o'' = 9\,\text{kW/m}^2$ is maintained at the tube surface. Assume air properties as: $\rho = 1.164\,\text{kg/m}^3$, $k = 0.02588\,\text{W/m}\cdot\text{°C}$, $\nu = 1.608 \times 10^{-5}\,\text{m}^2/\text{s}$, $\text{Pr} = 0.7282$ and $c_p = 1007\,\text{J/kg}\cdot\text{K}$.

(a) Determine the air outlet temperature.

[5 marks]

(b) Find the Reynolds number of the air flow.

[4 marks]

(c) Verify if fully developed condition is attained at the tube outlet.

[2 marks]

(d) Estimate the surface temperature of the tube at the outlet.

[8 marks]

(e) Coordinate x axis is defined along flow direction and originates from the centerpoint of the cross sectional area at entrant. If the heat flux at the tube surface depends on coordinate x and is specified by,

$$q'' = q_o'' \left(1 - \cos\frac{2\pi x}{L}\right),$$

derive the air temperature as a function of x, starting from the steady state energy balance for the tube of width dx. You may leave your expression in symbols. Hence, *find* the air outlet temperature. *Compare* with the answer in part (a) and comment.

[6 marks]

Note: Nusselt number correlations for fully developed flow in tube are :

1. $Nu_D = 0.023\text{Re}_D^{0.8}\,\text{Pr}^n$, $n = 0.4$ for *heating* and 0.3 for *cooling*, turbulent flow.
2. $Nu_D = 4.36$ for uniform surface heat flux, laminar flow.
3. $Nu_D = 3.66$ for uniform surface temperature ,laminar flow.

Continued...

Question 3

(a) Consider a parallel flow, concentric heat exchanger, designed to cool a fluid having a specific heat of 3200 J/kg·K and flowing at 1.5 kg/s from 90 °C to 40°C with chilled water having a specific heat 4180 J/kg·K, supplied at a temperature of 10 °C and a flow rate of 2.5 kg/s. Assuming an overall heat transfer coefficient of 1000 W/m^{2}·K, determine:

(i) the heat transfer rate,

[4 marks]

(ii) the exit temperature of chilled water and

[3 marks]

(iii) the required heat transfer area.

[5 marks]

(b) The temperature distribution for an infinitely long fin is given as $\frac{T-T\infty}{Tb-T\infty} = e^{-\sqrt{\frac{hP}{kA_c}}\,x}$. Show that there is *no heat loss* from the *fin tip* for such temperature distribution. All symbols carry the usual meanings. **[3 marks]**

(c) Consider a copper circular fin A of 2 mm in diameter attached to a heated surface whose base temperature is T_b = 200 °C. The fin is at an air environment with T_∞ = 30 °C and h = 50 W/m^{2}·K. The thermal conductivity of fin A is k =401 W/m·K.

(i) Find the heat transfer rate, q_f from fin A assuming that the fin is long.

[4 marks]

Note: You may find the Appendix useful for part (c) (i).

(ii) A research engineer sets $\frac{T_{x=L}-T\infty}{Tb-T\infty} < 0.01$, so that temperature at the fin tip, $T_{x=L}$ is approximately equal to the air temperature, T_∞ . For such condition, determine the minimum fin length for which the long fin assumption applies.

[2 marks]

Note: You may find the temperature distribution in part (b) useful for part (c) (ii).

(iii) A research engineer would like to replace fin A with fin B of a rectangular cross section, having thickness, t = 2 mm, and width, $w >> t$. How will this change affect the minimum fin length required as in part (ii) ? By considering the fin efficiency, do you agree with the fin replacement if both fins have the same length?

[4 marks]

Continued...

Question 4

(a) Sketch the thermal radiation network for the case of radiation exchange between two gray surfaces, 1 and 2, labelling all nodes and resistances. Write down without proof the equation to calculate the heat transfer between them.

[8 marks]

(b) Sketch the thermal radiation network for the case of radiation exchange among three gray surfaces, 1, 2 and 3, labelling all nodes and resistances.

[5 marks]

(c) Consider the radiation exchange among three gray surfaces, 1, 2 and 3. The heat transfer from surface 1 is 27,600 W, and from surface 2 is -2,130 W. The black emissive power at surface 1 is 13,614 W/m^2, and at surface 2 is 3,544 W/m^2. The radiosity at surface 1 is 11,418 W/m^2, and at surface 3 is 1,452 W/m^2. The area of surface 2 is 3.14 m^2.

(i) Calculate the surface resistance at surface 1.
(ii) If the surface resistance at surface 2 is 0.478 m^{-2}, find the emissivity and the radiosity at surface 2.
(iii) If surface 3 is black, find the temperature of surface 3.
(iv) What is the heat transfer from surface 3?

[12 marks]

Note: Take the Stefan-Boltzmann constant to be 5.67×10^{-8} $W/m^2 \cdot K^4$.

Continued...

APPENDIX: Heat loss q_f for fins of uniform cross section

Tip Condition ($x = L$)	Fin Heat Transfer Rate q_f
Convection heat transfer: $h\theta(L) = -kd\theta/dx\|_{x=L}$	$M\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$
Adiabatic $d\theta/dx\|_{x=L} = 0$	$M \tanh mL$
Prescribed temperature: $\theta(L) = \theta_L$	$M\dfrac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$
Infinite fin ($L \to \infty$): $\theta(L) = 0$	M

where $\theta = T - T_\infty$, $m = \sqrt{\dfrac{hP}{kA_c}}$, $M = \sqrt{hPkA_c}\ (T_b - T_\infty)$.

End of Paper